

is set on a solid masonry base built up from the ground, so that the least movement will be transmitted. The slightest quiver of this base disturbs a cup of mercury, which makes an electrical connection that starts the large cylinder carrying the record paper, revolving slowly, and also makes three ink dots on the face of the clock, the first at the hour, the second at the minute and the third at the second. On the record sheet, which is lamp-black paper, rest two points, so hung that they are practically undisturbed by any trembling of the earth, and so are known as immovable points. One of these records the vertical and the other the lateral movements.

When an earthquake occurs the pens remain stationary, while the movements of the cylinder, which are the same as the ground at that place, make a tracing indicative of the magnitude and directions of the shock.

### ON THE COLOR AND THE POLARIZATION OF BLUE SKY LIGHT.

By N. ERNEST DORSEY, Ph. D., dated Johns Hopkins University, September 10, 1900.

The color of the sky on a bright, clear day is familiar to all. In the zenith it is of a deep blue, but becomes more mixed with white as the point observed approaches the horizon where, when the sun is low, it may take on rich tints of red and orange. The exact character and intensity of the color depends directly upon the condition of the atmosphere and, with the transparency of the air, form the most important data for the predictions of the local weather prophet, that old, and often unschooled, man who has probably passed his entire life within the confines of a single county and by long experience has learned to foretell the weather twelve hours or more in advance with an accuracy which, considering the conditions, is truly remarkable. The professional meteorologist, on the other hand, has given the subject but scant attention, although the cause of the phenomenon has been discussed by philosophers and physicists ever since the belief in the possibility of at least a partial explanation of the physical world first entered the mind of man.

The story of the ideas held at various times to account for the color of the sky runs parallel with the history of science. Indeed, in science, as nowhere else, are we compelled to recognize that "history repeats itself." In tracing the elaboration of the theory of each and every phenomenon we find a résumé of the various steps by which the present position of science has been reached. In some cases the course is run in a few months or years; in others centuries are required, and in still others we may be so near the great unknowable that we may never be able to take a single step forward.

The theory of the color of the sky, as implied above, has been of slow growth. When this growth began no one can tell, probably in the mists that hide the beginnings of human knowledge. One of the first explanations that we find in scientific literature—almost barbarous in its crudity and unsupported by fact or theory—is the speculation of Leonardo da Vinci<sup>1</sup> that the blue of the sky is due to the mixing of the white sunlight, reflected from the upper layers of the air, with the intense blackness of space. This corresponds to the speculative stage of science, the age of the philosophers. Very closely related to the speculative, indeed we may be justified in considering it as a mere incident of this, is what we may call the inherent property stage. Under the dominion of this mental state the color of the sky was thought to be rendered intelligible by the statement that it is the inherent property of air,<sup>2</sup> or of unknown particles floating in the air,<sup>3</sup> to reflect blue and to transmit red and orange light. This is a true explanation *ignotum per ignotius*, and leaves those who accept it in a worse condition than they were before, for no one is so hopelessly ignorant as he who thinks he knows. In the next step analogy comes into play; this is a most valuable and effective tool for the scientist endowed with a vivid

scientific imagination and with a keen, clear insight into nature, but for others a most dangerous weapon. In this case it is wielded by no less an intellect than that of Sir Isaac Newton. In his optical investigations, about 1675, he had been led to a study of the colors produced when light is reflected from thin films of transparent substances; these he found to depend upon the thickness of the film. When it is very thin it appears black; as the thickness gradually increases it becomes blue, then white, yellow, red, etc. This blue which first appears, and which may be seen surrounding the black spot on soap bubbles, Newton termed the "blue of the first order," and he thought it was of the same tint as the blue of the sky. Analogy now steps in and suggests that the color of the sky is due to the reflection of sunlight from transparent bodies of such a size that the reflected light is the blue of the first order. This was Newton's belief,<sup>4</sup> and he thought that the reflecting particles were small drops of water.

This is the first theory worthy of serious consideration, and was for a time generally accepted as correct. But no theory based on pure analogy can be regarded as final: it must first be subjected to the most severe analytical and experimental criticism of which we are capable. If it stands the test, well and good; if not, it must be rejected. In 1847 Clausius<sup>5</sup> subjected Newton's theory to a strict mathematical analysis, and proved that, if the blue of the sky is the blue of the first order, resulting from the reflection of light from transparent bodies, these bodies must be in the form of thin plates or thin-walled, hollow spheres. They can not be solid drops or spheres, for then astronomical objects would never be sharply defined; a star would appear as large as the sun, and the sun, immensely larger; all celestial objects would appear as large discs of light, brightest at the center and fading out gradually toward the edges. For this reason Clausius, believing the blue to be that of the first order, held the opinion that the reflecting bodies were hollow spheres, or vesicles of water. The belief in the existence of so-called "vesicular vapor" did not originate with Clausius, but was a relic which had persisted from the speculative age<sup>6</sup> to this time in spite of its a priori improbability, and the natural opposition so caused. As the theory of vesicular vapor has now been completely discarded we need say no more about it; the real value of the work of Clausius lies in the proof that the light from the sky can not be due to the regular reflection of sunlight from small drops of water.

The experimental test was applied by Brücke,<sup>7</sup> who pointed out that the blue of the sky is radically different from the blue of the first order. Thus, the era of analogy began to give way to that of experimentation and analysis, which must go hand in hand; experimentation acts as guide, analysis is the engineer, bridging the crevasses which can not otherwise be crossed, and the prophet pointing out the logical results of each assumption. The object of this, the last stage yet reached in the progress of science, is to bring the new phenomena into line with the old, to show how they are the necessary consequences of other facts which are better known. Each fact is referred to some better known fact, and the best known facts are regarded as axioms, postulates, or unexplainable experimental data, or it may be as mere uncontradicted assumptions, according to the mental condition of the man pronouncing judgment upon them.

Before going farther it will be well to see what was now known in regard to the polarization of the sky, for from now on this and the theory of the color of the sky go along together. But right here we may mention that at various times during the orderly development of the theory of blue sky

<sup>1</sup> Optics, Book II.

<sup>2</sup> Crelle's Jour. für Math., 34, pp. 122-147, 1847; 36, pp. 185-215, 1848; Pogg. Ann., 72, pp. 294-314, 1847.

<sup>3</sup> Leibnitz, Opera Omnia, II. Part II, p. 82, edition of 1768.

<sup>4</sup> Pogg. Ann., 88, pp. 363-385, 1853.

<sup>5</sup> Traité de la Peinture, also quoted in Gehler's Wörterbuch, § Atmosphäre.

<sup>6</sup> Marriotte, Oeuvres I, p. 299. <sup>7</sup> Honoratus Fabri, Optical Essays.

light we find shooting up other ill-considered and short-lived suggestions for explaining the phenomenon; such as the suggestion that the color is purely subjective<sup>8</sup>; that it is due to ozone,<sup>9</sup> etc.

The polarization of light was discovered in the last part of the seventeenth century by Huygens, but remained an isolated phenomenon until early in the present century, when Malus (1808) discovered that light reflected from glass was polarized. This aroused renewed interest in the subject of polarized light and of the transmission of polarized light through crystals. While engaged in this work (1811) Arago<sup>10</sup> accidentally turned toward the sky a piece of mica which he was examining by means of a crystal of Iceland spar, when he immediately noticed that the two images formed by the spar became brightly colored with complementary tints. He found that the coloration varied in intensity with the orientation of the crystal and with the position of the point of sky observed. It was greatest at a point nearly 90° from the sun and decreased on each side of this circle. These observations proved that the sky light is itself polarized and that the maximum of polarization is approximately 90° from the sun. It was also found that in general the plane of polarization is that which includes the sun, the point observed, and the observer.

These facts were regarded as positive proof that the light from the sky is regularly reflected sunlight. But when light is reflected from a transparent body, the maximum of polarization occurs when the tangent of the angle of incidence is equal to the index of refraction of the body referred to the surrounding medium as unity. If the reflecting particles are water, the region of maximum polarization is about 74° from the sun; hence, the blue sky light can not be reflected from water, as Newton, Clausius, and others assumed. On the contrary, if this light is regularly reflected sunlight, the reflecting bodies must have an index of refraction which is nearly equal to unity; hence several suggested that it was due to the reflection of sunlight on its passage between layers of air of slightly different densities, or, perhaps, between the oxygen and nitrogen of the air, or, perhaps, from the ether to one or other of these gases. In all these cases the light would be exceedingly weak, and it has generally been admitted that at best this can account for but a small part of the observed phenomena.

So matters stood until Brücke<sup>11</sup> (1853) proved that the light scattered from a turbid medium is blue, and Tyndall<sup>12</sup> (1869) performed his beautiful experiments on this subject, in which he showed that when the particles causing the turbidity are exceedingly fine (too small to be seen with a microscope) the scattered light is not only a magnificent blue but is polarized in the plane of scattering, the amount of polarization is a maximum at an angle of 90° with the incident light, and the definition of objects seen through it is unimpaired by the turbidity. Here, for the first time, all the essential features of sky light were reproduced in the physical laboratory. This experiment of Tyndall's was at once recognized as giving the key to the problem. Lord Rayleigh<sup>13</sup> (1871-1899) undertook the analytical treatment of the subject and proved that when white light is transmitted through a cloud of particles, small in comparison with the cube of the shortest wave length present in the incident light, the light scattered laterally is polarized in the plane of scattering, the maximum of polarization is at 90° to the incident light, and the intensities of the components of the scattered light vary inversely as the

fourth powers of their wave lengths; no account is taken of the light which has undergone more than a single scattering. All these facts have been shown to agree with the phenomena observed in the laboratory when light is passed through turbid media. Recently (1899) Lord Rayleigh<sup>14</sup> has shown that in this way about one-third of the total intensity of the light from the sky may be accounted for by the scattering produced by the molecules of oxygen and nitrogen in the air, entirely independent of the presence of dust, aqueous vapor, or other foreign matter.

We can not do better than to stop here for a few moments to consider Lord Rayleigh's physical explanation of the scattering produced by small particles.<sup>15</sup> On this theory light is propagated as transverse vibrations of the atoms or corpuscles of a medium that acts like an elastic solid; it is something like the waves that go along a rope when one end is shaken, only in the case of light we are dealing with no rope but with an infinite medium. When we speak of a beam of light being polarized we mean that all the vibrations in this beam take place in the same plane, and the plane of polarization may be defined as the plane passing through the direction of propagation of the light but perpendicularly to the direction of the vibrations, and therefore perpendicular to the plane of vibration. Now, imagine a beam of parallel light advancing through a homogeneous medium, say the free ether, in a vertical direction; there will be no light propagated except in this direction; there will be no scattered light. If, however, there exist in it particles optically denser than the ether, but small as compared with the wave length of light, then light will be scattered laterally by these. Indeed, the effect of these particles is to locally increase the effective inertia of the ether, whereas the rigidity remains unaltered; therefore, when a wave advancing through the medium reaches one of these particles, the displacement of the medium at this point is less than it would be were the particle absent. If we should apply to each particle a suitable force (which of course must be in the direction of the displacement and proportional to the difference of the densities of the particle and of the ether) we could restore the amplitude to the value it would have were the particle absent; under these conditions everything would go on as though there were no particle in the ether, and consequently there would be no scattered light, i. e., we should have neutralized the effect of the particle by the application of this force. Hence, on the other hand, we would have the same scattered light if the particle were absent and we should apply to this portion of the ether this force reversed in direction, that is to say, each particle acts as a center of a certain harmonic force acting upon the surrounding ether. Such a force will send out a plane polarized wave, whose intensity is symmetrical about the direction of the force as axis; it is zero in the direction of the force, and a maximum in the plane perpendicular to this direction.

The exact effect of such a force has been investigated analytically by Stokes<sup>16</sup> and also by Lord Rayleigh<sup>17</sup>. The displacement in the wave sent out by it is

$$\xi = \frac{F \sin \alpha}{4 \pi b^2 D r} \cos \frac{2 \pi}{\lambda} (b t - r)$$

if the force is  $F \cos \frac{2 \pi b t}{\lambda}$ ; where  $r$  is the distance from the

center of force to the point where the displacement is measured;  $\alpha$  is the angle between the direction of the force and the line joining the point considered to the center of force or the mean position of the disturbing particle;  $b$  is the velocity of

<sup>8</sup> Muncke, quoted in Gehler's Wörterbuch, art. Atmosphäre; Nichols, Phil. Mag. (5), 8, pp. 425-433, 1879; and Proc. A. A. A. S. 34, p. 78, 1885.

<sup>9</sup> Hautefeuille et Chappuis, Comptes Rendus, 91, pp. 522-525, 1880.

<sup>10</sup> Astronomie Populaire, 2, pp. 99-102; Oeuvres, 7, pp. 394 and 430.

<sup>11</sup> Pogg. Ann., 88, pp. 363-385, 1853.

<sup>12</sup> Phil. Mag. (4), 37, pp. 384-394, 1869; (4), 38, pp. 156-158, 1869.

<sup>13</sup> Phil. Mag. (4), 41, pp. 107-120, 274-279, 447-454, 1871; (5), 12, pp. 81-101, 1881 (5), 47, pp. 375-384, 1899.

<sup>14</sup> Phil. Mag. (5), 47, pp. 375-384, 1899.

<sup>15</sup> Phil. Mag. (4), 41, pp. 107-120, 1871.

<sup>16</sup> Math. and Phys. Papers II, pp. 243-328.

<sup>17</sup> Phil. Mag. (4) 41, pp. 107-120, 1871.

light;  $D$  the density of the ether;  $\lambda$  the wave length of the light sent out by the force; and  $\pi$  is the ratio 3.1416.

If the displacement in the incident wave is  $A \cos \frac{2\pi b t}{\lambda}$ , the force we must apply to the particle to restore the displacement to its natural value is

$$T(D'-D) A \left( \frac{2\pi b}{\lambda} \right)^2 \cos \frac{2\pi b t}{\lambda},$$

where  $D'$  is the optical density of the particle and  $T$  is its volume; therefore,

$$\xi = A \frac{D'-D}{D} \frac{\pi T}{r} \sin \alpha \cos \frac{2\pi}{\lambda} (b t - r),$$

and the intensity of the scattered light is for each particle

$$A^2 \left( \frac{D'-D}{D} \right)^2 \frac{\pi^2 T^2}{r^2 \lambda^4} \sin^2 \alpha.$$

Since the particles are in motion the light scattered from different particles will have no definite phase relation; hence, to get the effect of a cloud of such particles we must add the intensities of the light sent out by each separate particle.

If the incident light is plane polarized,  $\alpha$  will be a constant for any given direction from the incident beam, and the total intensity of the light scattered in this direction will be

$$A^2 \left( \frac{D'-D}{D} \right)^2 \frac{\pi^2 \sin^2 \alpha}{\lambda^4} \Sigma \frac{T^2}{r^2}.$$

If the incident light is unpolarized, the intensity of the light scattered at an angle  $\beta$  with the direction of the incident beam will be

$$A^2 \left( \frac{D'-D}{D} \right)^2 \frac{\pi^2 (1 + \cos^2 \beta)}{\lambda^4} \Sigma \frac{T^2}{r^2},$$

where  $\Sigma \frac{T^2}{r^2}$  denotes the sum of  $\frac{T^2}{r^2}$  for all the scattering particles in the line of vision. In none of this have we taken account of the light that has undergone more than a single scattering. If we denote the mean of the square of  $\frac{T}{r}$  by  $\frac{T_1^2}{r_1^2}$  and let  $N$  denote the number of particles in the line of vision, we can write the expression for the intensity of scattered light in the form

$$A^2 \left( \frac{D'-D}{D} \right)^2 \frac{\pi^2 (1 + \cos^2 \beta)}{\lambda^4} \frac{N T_1^2}{r_1^2}.$$

What are the assumptions we have made in this treatment? They are:

1. Every scattering particle is so small that when a wave of length  $\lambda$  passes through the medium containing it the force is the same at every point of the particle, i. e., that each particle is small as compared with the cube of the shortest wave length of the incident light.

2. The particles are so far apart that their effect upon the velocity of light through the medium is negligible; i. e., that the particles are far apart as compared with the longest wave length with which we are dealing.

In his discussion of Lord Rayleigh's equations, Crova<sup>18</sup> claims there is a third assumption, viz, that the number of particles in unit of volume must be sensibly the same for all sizes of particles. He says: "La formule  $\frac{1}{\lambda^4}$  est basée sur l'hypothèse que le nombre  $N$  de corpuscules contenus dans l'unité de volume d'air est sensiblement le même pour toutes les dimensions de ceux-ci." Mascart<sup>19</sup> is of the same opinion. This is evidently wrong. The expression

$$A^2 \left( \frac{D'-D}{D} \right)^2 \frac{\pi^2 T^2 \sin^2 \alpha}{r^2 \lambda^4}$$

applies to particles of *all* sizes, provided they are small in comparison with the cube of the shortest wave length. The light from a cloud of such particles is merely the sum of the light from the individual particles; the relative number of particles of various sizes does not enter into the consideration at all; indeed, the composition of the light is entirely independent of all consideration of the number and size of the particles other than as specified in the two assumptions we have named. Particles of a size intermediate between these small ones and those larger ones that reflect light regularly produce effects as yet unknown, and are not amenable to this analysis.

From Lord Rayleigh's expression for the intensity of the scattered light we may conclude, if the manifold or multiply scattered light may be neglected:

1. The scattered light is polarized in the plane of scattering and the amount of its polarization is  $\frac{1}{1 + \cos^2 \beta}$ , being a maximum (completely polarized) when the direction of scattering is perpendicular to the direction of propagation of the incident light.

2. The intensity of the scattered light varies  $\frac{1}{\lambda^4}$  times the intensity of the incident light. Its color or wave length is independent of the direction of scattering.

3. The maximum intensity of the scattered light is in a direction almost coincident with that of the incident light and in the opposite direction, and the minimum is in the plane perpendicular to this.

4. The larger the particles (provided the assumptions above are fulfilled), the more intense is the scattered light.

As stated above, we know little, if anything, about the action of particles that are just too large for this treatment to apply, but in another of his papers<sup>20</sup> Lord Rayleigh has solved to the next approximation (on the electro-magnetic theory) the special case of spherical particles, and finds that the light scattered should vary as the inverse eighth power of the wave length. In the air there are surely some particles approximately fulfilling these conditions, and hence the sky should appear bluer than indicated by the simple theory we have just considered. But we have not yet bridged the gap between "very small" particles and those large enough to give regular reflection.

We have thus far neglected the multiply scattered light, but this increases in intensity as the square and higher powers of the number of particles per unit volume, while the once-scattered light increases as the first power only. Hence, for a cloud of particles the multiply scattered light may easily become appreciable. This again increases the proportion of the blue.

For all these reasons the color of the light from the sky should be expressed by the sum of a series of terms of powers of the reciprocal of the wave length; not by a single term, as is ordinarily attempted. Crova,<sup>21</sup> endeavoring to express the intensity by a single term of the form  $\frac{k}{\lambda^n}$ , found values of  $n$  varying from 2 to 6 under different conditions, the average being about 4, as Lord Rayleigh<sup>22</sup> and Captain Abney<sup>23</sup> had found. But in no case could  $n$  be determined so as to give more than a fair agreement. As we have seen, values of  $n$  higher than 4 are to be expected; the lower ones are to be accounted for by the lateral scattering caused by the particles between the observer and the source of the scattered light which reaches him, by the absorption of the short waves by

<sup>18</sup>Phil. Mag. (5), 12, pp. 81-101, 1881.

<sup>21</sup>Comptes Rendus, 112, pp. 1176-1179, 1246-1247, 1891.

<sup>22</sup>Phil. Mag. (4), 41, pp. 107-120, 1871.

<sup>23</sup>Phil. Trans., 178, part I, pp. 251-283, 1887; also Proc. Roy. Soc., 42, pp. 170-172, 1887.

<sup>18</sup>Comptes Rendus, 112, pp. 1176-1179, 1891.

<sup>19</sup>Traité d'Optique, III, p. 386, Sec. 731.

interposed water vapor, and by the admixture of white light reflected from the larger particles.

The scattering of which we have been speaking is evidently different from what we ordinarily mean by reflection; the latter assumes that the reflecting surfaces have an area large as compared with  $\lambda^2$ ; whereas, scattering assumes that the volume of the particle must be small as compared with  $\lambda^2$ .

Such is in outline the theory and the main facts in regard to the cause of blue sky light; but there are several secondary features, which must be now considered. The sky is bluer in the zenith than elsewhere, evidently because the path traversed by the scattered light is here the shortest, so that it suffers less admixture with white light and less absorption of blue light. Conversely it should be less blue near the horizon, and when the sun is low may take on a red or orange tint, as we know is the case. The light from the zenith is most intense when the sun is nearest it, as at true noon, and its blue is least pure at the hottest part of the day, on account of the maximum amount of large particles of dust and vapor constituting the haze existing at this time.

Arago discovered that there is a point, about  $15^\circ$  above the point diametrically opposite the sun (the antisolar point), where the polarization is zero;<sup>24</sup> between this and the horizon the polarization is horizontal. Babinet<sup>25</sup> discovered a similar point above the sun, and Brewster<sup>26</sup> found one below it. Between the neutral points discovered by Babinet and by Brewster the polarization is horizontal; below Brewster's point and above Babinet's it is vertical. For a little way on each side of the neutral points the plane of polarization is inclined at about  $45^\circ$  to the vertical. This seemed to indicate that superposed upon the polarization resulting from the scattering of direct sunlight is a horizontal polarization due to some secondary cause. It was soon suggested that the horizontal polarization is due to a secondary scattering of the light coming from the lower layers of the atmosphere, and this has generally, but not universally, been accepted as the most probable explanation. Other neutral points have been observed under rare conditions.

The positions of the neutral points, the amount of polarization, the position of the point of maximum polarization, as well as the color of the sky, are intimately connected with other meteorological phenomena, but as yet the observations have been so meager, made under such dissimilar conditions and by such various forms of apparatus, that it is nearly impossible to tell what is the true connection. Cornu<sup>27</sup> says:

D'une manière générale, la quantité de lumière polarisée est liée de la manière la plus directe avec l'état de l'atmosphère, à tel point que j'ai été amené à conclure que cette proportion était un coefficient caractéristique de l'état de l'atmosphère. La plus grande pureté du ciel correspond à la plus grande proportion de lumière polarisée, les cirrus et la brume diminuent cette proportion jusqu'à rendre nulle, lorsque le ciel devient couvert. \* \* \* Ce qui est particulièrement intéressant, c'est que les moindres changements dans l'état atmosphérique sont décelés par le polarimètre avec une grande sensibilité, plusieurs heures avant que les phénomènes précurseurs (variations barométriques, halos, phénomènes divers optique atmosphérique) aient commencé à signaler un changement.

Sous ce rapport, il serait utile de poursuivre méthodiquement ces observations, et de comparer les variations polarimétriques aux autres éléments caractéristiques de l'atmosphère. \* \* \* La proportion de lumière polarisée augmente à mesure que le soleil descend sous l'horizon, jusqu'à un certain maximum, après lequel la polarisation disparaît rapidement. La loi d'accroissement avec le temps de cette proportion est fort importante, car elle me paraît devoir donner la répartition de la brume dans l'atmosphère suivant la verticale; en effet, si l'accroissement est rapide, c'est que les couches inférieures sont brumeuses et les couches supérieures transparentes, si l'accroissement est lent, l'atmosphère est plus homogène.

[Translation]

In a general way, the amount of polarized sky light is connected in

<sup>24</sup>Oeuvres, VII, p. 344.

<sup>25</sup>Pogg. Ann., 51, pp. 562-564, 1840.

<sup>26</sup>Pogg. Ann., 66, pp. 456-457, 1845.

<sup>27</sup>Limoges Meeting of French Assoc. Adv. Science, 1890, pp. 267-270.

so direct a manner with the condition of the atmosphere that I have been led to think that it is characteristic of the state of the atmosphere. The greatest clearness of the sky corresponds to the greatest amount of polarization; cirrus and fog decrease the amount, and even completely destroy the polarization when the sky is overcast. \* \* \* What is particularly interesting, is that the least change in the state of the atmosphere is plainly shown by the polarimeter several hours before other precursory phenomena (barometric variation, halos, and various other optical phenomena) have begun to indicate a change.

Under these conditions it would be useful to carry out these observations in a methodical manner, and to compare the polarimetric variations with other elements characteristic of the atmospheric condition. \* \* \* The amount of polarization increases as the sun sinks below the horizon until it reaches a certain maximum, after which the polarization rapidly disappears. The law of this increase of polarization with the time is very important, for it appears to me to give the vertical distribution of fog in the atmosphere; indeed, if the increase is rapid the lower layers are foggy and the upper ones transparent; if the increase is slow, the atmosphere is more homogeneous.

In short, the more fog or cloud there is present the less the amount of polarization and the less pure is the blue of the sky.

The most extensive series of observations are those of Rubenson<sup>28</sup> and of Brewster<sup>29</sup> on the polarization, and of Crova<sup>30</sup> and Abney<sup>31</sup> on the color of the light from the sky. The first limited himself to observations made in fairly clear weather, and the second directed his attention principally to the determination of the positions of the various neutral points. Rubenson and most other observers have laid special stress upon the intensity of the polarization at its maximum point in the vertical circle through the sun. This is undoubtedly the point where observations can be most easily taken, and those so obtained must be of great meteorological value, but the interpretation of them is rendered difficult by the variation in the length of the path of the scattered light at different times of the day. At sunrise and sunset the point observed is the zenith, and the path is a minimum; while at noon, if the observer be in the tropics, the point observed may be on the horizon, and the length of the path a maximum. For other positions on the surface of the earth the variation in length of path is less than this.

On the other hand, unless we observe a point of maximum polarization the observations will be vitiated by every error in determining the position, with respect to the sun, of the point observed. Though other objections may be urged, it has occurred to me that for meteorological prediction the most valuable data would be obtained from continuous observations of the amount of the polarization of the light from points of the sky on the horizon and  $90^\circ$  distant from the sun. These are points of maximum polarization; these observations will give a kind of integration of the atmospheric conditions over a large area, and the length of path being the same at all times the observations should all be comparable, except for the varying angle of illumination of the surface of the earth, which, unless the nature of the surface differs greatly in different directions, I think would hardly affect the results appreciably, except, perhaps, when the sun is near the horizon. No one, to my knowledge, has carried out such a series of observations, hence the suggestion is advanced with great hesitation.

Since the color of the sky is independent of the angular distance of the point observed from the sun, being a function of only the state of the atmosphere and the thickness of the stratum observed, there is but little choice in the altitude of the point where we make the color observations. But since the blue is a maximum in the zenith this is rather to be pre-

<sup>28</sup>Nova Acta Reg. Soc. Upsala (4), 5, 1864, Mémoire sur la Polarisation, etc.

<sup>29</sup>Phil. Mag. (3), 31, pp. 444-454; (4), 30, pp. 118-129, 161-181; (4), 33, pp. 290-304, 346-360, 455-465.

<sup>30</sup>Ann. de Chim. et de Phys. (6), 20, pp. 480-504, 1890; (6), 25, pp. 534-567, 1892.

<sup>31</sup>Phil. Trans., 178, part 1, pp. 251-283, 1887.

ferred, for a slight error in the position of the point observed will here produce the least effect.

Whatever point or points are observed, the fact remains that careful observations on the color and the polarization of the light from the sky will give us data determining the amount and size of the particles floating in the air, be they dust or water, and, as any change in the state of the atmosphere will affect these quantities, such observations should be of ever increasing importance to meteorology. First, however, we must have a long series of observations taken at different places and under all conditions, with exact meteorological data obtained at the same time and place, together with a description of the nature of the surrounding country. When these have been obtained it should be not very difficult to find means of using future observations with great success.

The results so far obtained can be interpreted only in the most general manner, as above; the daily and hourly variations and the subsidiary phenomena have not as yet been satisfactorily interpreted, and until this is done an abstract of the suggested views might be misleading. For this reason it seems best to limit ourselves to this short note which is intended merely to call attention to this interesting subject and to present in a more or less readable manner the facts and theory of the color of the sky. Those who wish to add to our knowledge on this subject will consult the original papers. *Résumés* will be found in the following articles:

1. James D. Forbes, on The Colors of the Atmosphere, considered with reference to a previous paper On the Color of Steam under certain circumstances. *Philosophical Magazine* (3), 14, pp. 419-426, 1839, and (3), 15, pp. 25-37, 1839; also in *Pogg. Ann.*, Erg. Bd. 1, pp. 49-78, 1842.

2. Sir David Brewster's Observations on the Polarization of the Atmosphere, made at St. Andrews in 1841, 1842, 1843, 1844, and 1845. *Phil. Mag.* (4), 30, pp. 161-181, 1865; also in *Trans. Roy. Soc. of Edinburgh*, 23, pp. 211-240, 1894; and in Keith Johnston's *Physical Atlas*, London.

3. R. Rubenson's *Mémoire sur la Polarisation de la Lumière Atmosphérique*. *Nova Acta Regiæ Societatis Scientiarum Upsaliensis* (4), 5, Fasc. 1, 1864.

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### MEXICAN CLIMATOLOGICAL DATA.

Through the kind cooperation of Señor Manuel E. Pastrana, Director of the Central Meteorologic-Magnetic Observatory the monthly summaries of Mexican data are now communicated in manuscript, in advance of their publication in the Boletín Mensual. An abstract, translated into English measures, is here given, in continuation of the similar tables published in the MONTHLY WEATHER REVIEW since 1896. The barometric means have not been reduced to standard gravity, but this correction will be given at some future date when the pressures are published on our Chart IV.

*Mexican data for September, 1900.*

Stations.	Altitude.	Mean barometer.	Temperature.			Relative humidity.	Precipitation.	Prevailing direction.	
			Max.	Min.	Mean.			Wind.	Cloud.
Durango (Seminario)...	6,243	24.07	87.8	50.0	64.4	60	4.80	ene.	se.
Leon (Guanajuato)...	5,934	24.33	82.6	53.4	67.5	67	2.23	sse.	e.
Mazatlan .....	25	29.86	92.8	72.7	83.3	80	14.18	nw.	se.
Merida .....	50	29.99	95.0	75.8	81.5	80	1.50	ne.	e.
Mexico (Obs. Cent.)...	7,472	23.08	77.0	50.9	62.8	68	2.51	n.	ne.
Morelia (Seminario)...	6,401	23.99	78.8	51.8	63.9	80	3.22	e.	e.
Puebla (Col. Cat.)....	7,112	23.37	77.0	51.8	65.7	81	5.09	e.	sw.
Saltillo (Col. S. Juan)...	5,399	24.83	83.3	56.1	69.6	73	4.46	n.	s.

### RECENT PAPERS BEARING ON METEOROLOGY.

W. F. R. PHILLIPS, in charge of Library, etc.

The subjoined list of titles has been selected from the contents of the periodicals and serials recently received in the library of the Weather Bureau. The titles selected are of papers or other communications bearing on meteorology or cognate branches of science. This is not a complete index of the meteorological contents of all the journals from which it has been compiled; it shows only the articles that appear to the compiler likely to be of particular interest in connection with the work of the Weather Bureau:

*National Geographic Magazine. Washington. Vol. 2.*

Garriot, E. B. West Indian Hurricane, September 1-12, 1900. P. 384.

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Marshall, A. Atmospheric Electricity and Dew-point. P. 495.

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Fergusson, S. P. Progress in Meteorological Kite Flying. P. 521.

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Borchgrevink, C. E. The "Southern Cross" Expedition to the Antarctic. 1899-1900. P. 381.

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Bruckner, E. Ueber den Einfluss der Schneedecke auf das Klima der Alpen. P. 193.

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### OBSERVATIONS FOR LOCAL THUNDERSTORMS AT SKYLAND, PAGE COUNTY, VA., SEPTEMBER, 1900.

By Messrs. W. H. and H. S. CRAGIN.

September 1.—8 a. m., 70°; 3 p. m., 81°; 9 p. m., 70°. Fair and slightly warmer, with light east winds.

September 2.—8 a. m., 70°; 3 p. m., 78°; 8 p. m., 67°. Fair and not so warm; light east winds, becoming high at night.

September 3.—8 a. m., 67°; 1 p. m., 76°; 8 p. m., 70°. Partly cloudy, with light east winds, becoming northwest at night. There was a little rain early in the morning of the 4th.